

# THE RETURN OF ASTROMATERIALS TO EARTH OVER THE NEXT DECADE

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## Introduction

We are entering a new and golden age of sample return missions. In the coming decade we will harvest samples from Comet P/Wild II and interstellar dust courtesy of the STARDUST Mission (Brownlee et al., 1997), an asteroid (probably 4660 Nereus or 1989ML) by the ISAS MUSES-C Mission (ISAS, 1997), and solar wind by the Genesis Mission. A sample return from Mars is also envisioned as early as 2008, and possibly one from the two moons of Mars. It is, however, sobering to realize that MUSES-C aims to return 3-10 g of sample, STARDUST will provide micrograms of comet and interstellar dust, and Genesis will harvest only few micrograms of atoms. The diminutive size of the returning samples may be a source of concern for petrologists used only to looking at hefty lunar rocks and meteorites.

How much sample is really needed to achieve prime science objectives, while maintaining a cost effective mission? The range of geological processes that we will want to address with these samples is staggering, encompassing not merely the entire history of the Solar system, but the history of the elements themselves. The interstellar processes include element formation, production and interactions with radiation, formation of organics, grain condensation and evolution, and interactions with magnetic fields. In the pre-accretionary (nebular) environment we wish to understand grain condensation, evaporation and recondensation, shock, radiation processing, solar energetic particle implantation, gas composition, the magnetic environment, and the evolution of organics. Finally, for solid bodies we wish to examine accretion history, shock, brecciation, impact gardening, metamorphism, aqueous alteration, weathering, exposure history, volcanism, fumarolic activity, differentiation, the magnetic environment, atmosphere evolution, and the evolution of organics.

Since 1981, NASA has supported asteroid and comet science by collecting dust grains from these bodies in the stratosphere, and making them available for analysis in laboratories worldwide (Warren and Zolensky, 1994). Over the succeeding 17 years, many new techniques have been developed for these painstaking analyses, by at least 24 different laboratories across the globe. Despite the fact that the particle supply has always exceeded the demand, the painstaking efforts required for most of the nano-scale analyses have resulted in only 1520 grains having been analyzed, with a total mass of only 0.52 micrograms. Thus we really require less sample for analysis than one might imagine.

## Sampling And Analysis Missions

### Missions In Preparation

*Genesis* is a NASA Discovery mission to collect and return to Earth approximately 5  $\mu\text{g}$  of solar wind atoms (for C through U, as the lighter atoms are of little interest here). The spacecraft is scheduled to lift off in 2001 and return to Earth in 2004, although, because the Sun is relatively fixed the launch period is very flexible. The spacecraft will be inserted into a halo orbit about the L1 Lagrangean point (0.01 AU from Earth) where collector arrays will be exposed to the solar wind. During a ~2 year exposure period, solar wind atoms will impact and be implanted into ultra-pure Si wafers, as well as a few other materials. Considerable efforts are being made to ensure low contamination levels both before and following solar wind collection. Following collection, the silicon wafers will be stowed into a sample return capsule for return to Earth at the Utah Test and Training Range (UTTR). These samples will then be transported to a

new curation facility located at NASA's Johnson Space Center, and will be handled, dissected and curated in dry nitrogen.

This is not the first return to Earth of solar wind, having been done on the surface of the Moon during the Apollo missions. However the collection duration will be orders of magnitude longer for Genesis, and contamination concerns are, this time around, paramount. Also, while collecting solar wind, the collection surfaces and surrounding structures will also be impacted by interplanetary dust particles and  $\beta$ -meteoroids. Efforts will be made to study the impact residues resulting from these impacting asteroidal and cometary particles, although nothing has been done to mitigate the detrimental effects these particles suffer during impact.

**STARDUST**, another NASA Discovery mission, will be the first sample return from a comet. Grains from a comet's coma will be collected into high-purity silica aerogel. The mission was launched on February 7, 1999. Thus it launched well before Genesis; however, it returns later. The STARDUST spacecraft will perform two swing-by orbits of the Earth to gather sufficient speed to reach the comet under optimal encounter conditions. The spacecraft reaches Comet Wild II on January 10, 2004 (or more properly, the comet, being faster, passes the spacecraft at this time). During passage through the cometary coma a tray of silica aerogel is exposed, and coma grains impact there and are captured. At the encounter velocity of 6 km/s, the grains will be decelerated as they pass into the aerogel, and come to rest there in a reasonably intact state (Barrett et al., 1992; Hörz et al., 1998). It is anticipated that approximately 1000 grains measuring less than 100  $\mu\text{m}$  will compose the harvest. In fact the majority of the sample will be under 10  $\mu\text{m}$ , and no grains larger than a few 100  $\mu\text{m}$  should be collected. The closest passage of the spacecraft will be engineered so that larger, potentially deadly, grains are not encountered. Following the coma passage the aerogel tray is closed for return to Earth.

There is also a dust impact mass spectrometer on board the STARDUST spacecraft, provided by J. Kissel and the Max Planck Institute. This is essentially the same instrument that flew on the Giotto mission to comet Halley a decade ago (Kissel and Krueger, 1987), and will be used to gather spectra of dust during the entire mission, including the coma passage. This instrument will be the best chance to obtain data on volatile grains, since the material collected in the aerogel will be heated and shocked significantly during the collection process. The dust impact mass spectrometer will also be used to study the composition of the interstellar grains.

There is also a third type of collection for STARDUST. In the past 5 years, analysis of data from dust detectors aboard the Ulysses and Galileo spacecraft have revealed that there is a stream of interstellar dust flowing through our solar system (Grun et al., 1993). These grains, of unknown mineralogy, generally measure less than 1  $\mu\text{m}$ , and so are impossible to collect at Earth by current techniques. Approximately 100 of these grains will be captured during favorable periods of the cruise phase of the STARDUST mission, during the 5 years the spacecraft spends getting to the comet. Analysis of these particles will represent the most difficult challenge of the post-flight operations.

The sample harvest from STARDUST will thus consist of ~1000 cometary grains, measuring less than 100  $\mu\text{m}$  each, and ~100 interstellar grains of mostly sub-micron size. The total mass of returned sample will be on the order of 1 mg. The sample return capsule will be open to air during atmospheric entry, which will occur in February, 2006, and will land at UTTR in western Utah.

The sample return capsule will be placed into a dry nitrogen environment immediately upon recovery on the Earth's surface. The capsule and its contents will be immediately flown to the curation lab at JSC. Approximately six months of preliminary investigation by a dedicated team will precede release of the sample to the general analysis community. This preliminary investigation period has the goal of documenting the initial state of the collected sample,

identifying the range of samples present, and assessing the best way to proceed with general sample distribution and analysis

The *MUSES-C* mission will be the first sample return mission by Japan's space science agency, The Institute of Space and Astronautical Science (ISAS). The goal of the mission is to return powdered or chipped samples from the surface (regolith?) of a small near-Earth asteroid, either Nereus or 1989ML (ISAS, 1996). The spacecraft will leave Earth in 2002, and rendezvous with the near Earth asteroid in 2004. Once in orbit, a rendezvous vehicle will separate from an orbiter. A "nano-rover" will drop from the former spacecraft, and hop around on the asteroid's surface making measurements and observing the collecting activities. The rendezvous vehicle itself will briefly touch down on the surface 2 or 3 times. During each of these touch-and-go landings a 5g projectile will be fired at the surface at a velocity of a 300 m/s, which will blast a small quantity of material from the surface. This liberated sample could be powder if there is an asteroidal regolith, or chips if bed-rock is exposed. In any case, on the order of 1g of material will be collected into a horn-shaped receptacle at each of three different sites. Following collection, the rendezvous vehicle re-mates with the orbiting spacecraft for Earth return. In January, 2006, the samples are returned to Earth within a hermetically-sealed capsule, and flown to the ISAS lab for 1 year of preliminary investigation in Japan. Following this period the samples will be made widely available, with approximately 10% of the sample mass coming to NASA for curation and wide distribution.

A *Mars Sample Return* mission is a NASA goal for early in the next millenium. The current scenario calls for a first sample return mission to land on Mars in 2003, collect core samples (with multiple g masses) from rocks and regolith, and then launch them into orbit within a small Martian ascent vehicle (MAV). These will be regolith grab samples and tens of mini core rock samples. Two years later, a second mission would land elsewhere and repeat this collection scheme. A spacecraft orbiting Mars will attempt to retrieve both orbiting samples, and return them to Earth in 2008.

Since the launch opportunities for Mars come along about every 2 years, slips of two year steps could occur. Of the sample-return missions described here, this is the only one where larger sample mass and grain size could make analysis of  $\mu\text{g}$  to g sized samples possible. Absolute ages that require mineral separates would then be possible. It is envisioned that these sampling missions would be repeated into the future.

It is now apparent that a quarantine will be imposed on any Mars samples returned to Earth (Space Studies Board, 1998). Thus, the details of sample preliminary investigation, distribution, and curation are now being decided.

### **Proposed Missions**

There are also sample return missions which are in the development, or pre-approval, stage. This means that the missions may or may not happen, and if they do, important details of the mission scenarios will undoubtedly change. Nevertheless, we introduce them briefly.

#### ***Aladdin***

The proposed Aladdin Discovery Mission will obtain samples from widely separated, carefully selected, well-characterized locations on the two Martian satellites, Phobos and Deimos, with a single launch and without the need for soft landing (Pieters et al., 1997). An innovative flyby "blast-and-grab" sample collection technique makes this possible. Targeted, unpowered projectiles are fired into the satellites' surfaces. Ejected particles are captured by the spacecraft as it flies by the surface. The low velocity of the flyby,  $\sim 1$  km/s, allows intact capture of the particles onto clean collector surfaces, preserving even organics and volatiles. High

resolution imaging and mapping spectrometry are used to map the moons' geology and to characterize the contexts of the samples, allowing global implications of sample science to be inferred. Radio science and imaging will provide measurements of mass and volume that allow density to be determined unambiguously; from this information, from stratigraphic relations of geologic units identified by imaging, and from the samples' mineralogy, the interior structure of the moons may be inferred.

The mission design allows sample return from both Martian satellites with a Delta-II launch in late May of 2003. The spacecraft arrives at Mars on Christmas eve of the same year, and eventually enters an elliptical orbit near Phobos' orbital plane and crossing both satellite orbits, such that the spacecraft makes a satellite flyby once every ~9 days. Optical navigation images of the satellites are collected to refine knowledge of the spacecraft position relative to the satellites.

Aladdin has five independent, successive collector "carpet" areas of 1,000 cm<sup>2</sup> each, separated by blank leader to prevent mixing of samples. Once a collector area has been exposed, it is retracted into the return capsule and blank leader is exposed until the next sample collection. The first two collection areas are used for Phobos samples; the third and fourth for Deimos samples; and the fifth for a torus sample. To collect a Phobos or Deimos sample, the appropriate collection area need be exposed only a few minutes, during which time it sees a negligible fluence of torus particles. The torus collection area is exposed for more than a month. Each area has a control segment, that is exposed to all ground and spacecraft environments but is shielded from the sample by designing the moderating baffle to divert incoming sample particles. The control strip validates sample science by measuring contamination levels.

The anticipated collected sample mass per moon is about 30 µg, or ~1100 particles each 10 µm in diameter. The return from the torus is poorly constrained, due to limited information on this phenomenon. The samples will be returned to Earth at UTTR in January, 2006.

Aladdin's miniature "regolith scoop samples" will provide information on the moons' mineralogic, elemental, and isotopic composition similar to that from the first Apollo 11 scoop sample of lunar regolith, which by itself provided the compositions of the maria and highlands and contained key evidence that led to the magma ocean hypothesis for lunar evolution which, in its essential form, remains accepted today. The impact and flyby speeds (1.0-1.4 km/s) are far lower than for STARDUST, and the flybys are repetitive allowing multiple sample acquisitions, providing the perfect test ground for evaluating and honing this new sample acquisition technique.

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